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Methods of Bridge Erection

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METHODS OF BRIDGE ERECTION

BY

ARTHUR WARD BUCKINGHAM

THESIS

FOR THE

DEGREE OF

BACHELOR OF SCIENCE

IN

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I recommend that the thesis prepared under my supervision by ARTHUR WARD BUCKINGHAM entitled Methods of Bridge Erection be approved as fulfilling this part of the requirements for the degree of Bachelor of Science in Civil Engineering.

C. W. Malcolm.

Asst. Professor of Structural Engineering.

Recommendation approved:

Ira O. Baker

Head of the Department of Civil Engineering.

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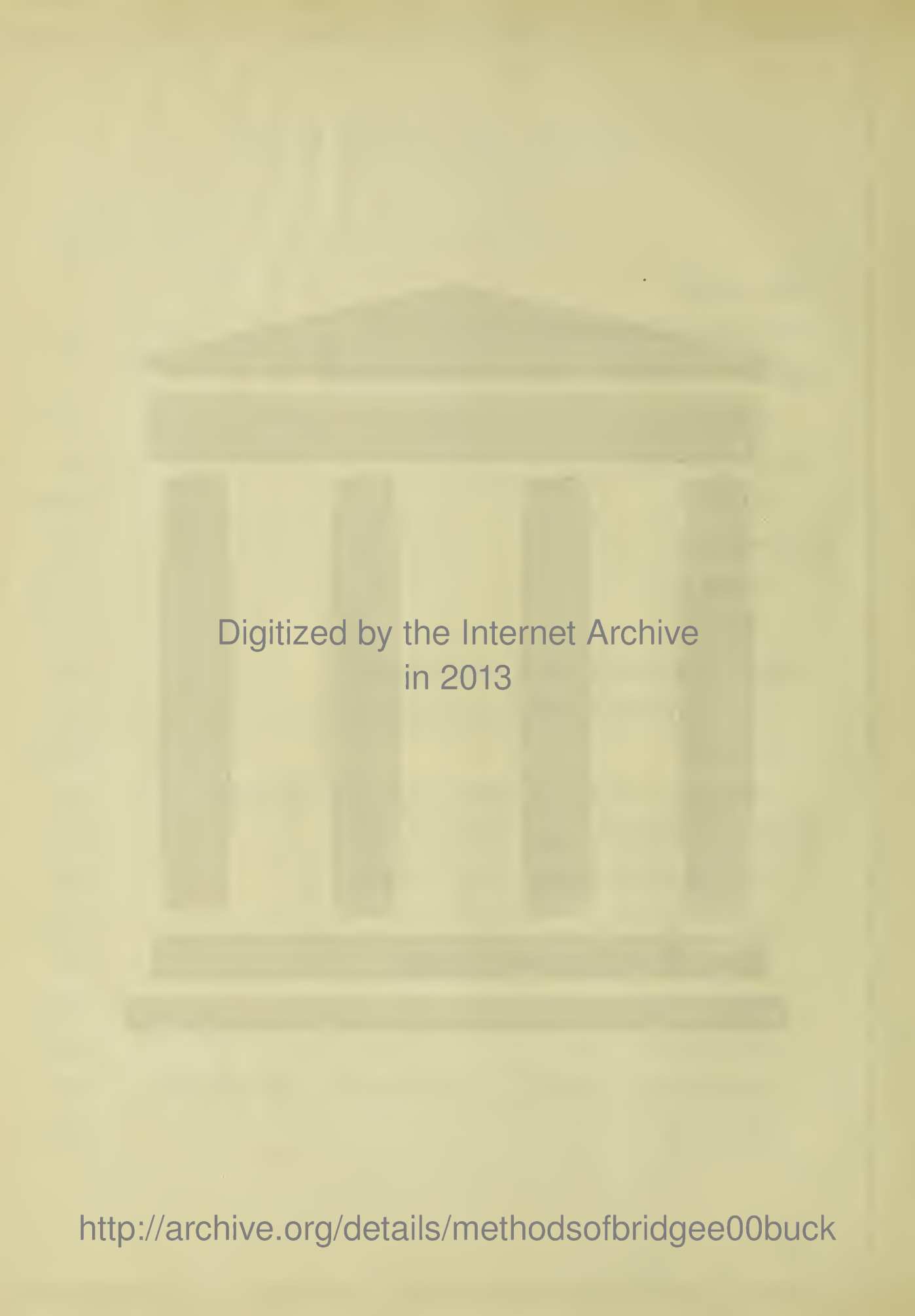
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INTRODUCTION

The remarkably short time now required to erect a bridge is largely due to the efficiency of the methods employed in handling the materials of construction. This efficiency is the result of a gradual development and improvement along the lines of bridge building. To construct bridges under the conditions of traffic which are met with to-day it has been necessary to develop a great variety of methods, and to invent new kinds of machinery for conveying and hoisting into place the heavy pieces of metal.

It is the purpose of this thesis to discuss in detail the various methods which have been used by contractors and bridge builders, with a view to bringing out the best methods to be employed at the present time. Owing to the extent of the bridge-building industry and to the great variety of peculiar conditions met with on the different types of bridges this discussion will be limited to the methods used in erecting steel stationary bridges. The greater number of the bridges, both large and small, which are built to-day will be included in this classification.

As practically all of the descriptive literature on the subject of bridge erection is in the form of miscellaneous engineering articles, it is believed that a discussion based upon these articles will be of considerable value.

This thesis will treat the subject of bridge erection in the following order: Introduction; History of Bridge Con-

struction; Methods of Erecting Steel Girder-Bridges; Methods of Erecting Small Truss-Bridges; Methods of Erecting Large Truss-Bridges; Comparison of the Methods Employed. In the "History of Bridge Construction" the development of bridge building will be briefly traced from the age of the Egyptians to the present day. Under the "Methods of Erecting Steel Girder-bridges" several girder bridges of various spans will be considered and the methods employed on these bridges will be described in detail. Under the "Methods of Erecting Small-Truss Bridges," the methods used on short span highway and railway bridges will be described in detail. In this discussion small truss-bridges will be considered as having a clear span length of one hundred fifty feet or less. Under "Methods of Erecting Large Truss-Bridges" the methods used on several bridges having a clear span greater than one hundred fifty feet will be described in a manner similar to that used for small truss-bridges. In a "Comparison of the Methods Employed" those methods best applicable to any given set of local conditions will be emphasized. These conditions may be either those which are governed by traffic or by geological conditions.

HISTORY OF BRIDGE CONSTRUCTION

In a discussion of the various methods used in erecting steel stationary bridges, it is interesting to note, briefly, the history of bridge construction itself. The need of some means of rapid communication across a body of water has always existed. In the early days the transportation of troops from one body of land to another was an important factor in the evolution of the bridge.

The early Egyptians were perhaps the first people to use the bridge. Their pictures of fortifications undergoing a siege show numerous wooden trestles and drawbridges. Although the early pile-trestle is hardly a bridge according to the popular conception of the term, still it must be considered the first appearance of anything of that nature. Historians tell us that the Greeks and Chinese also constructed bridges. They had a somewhat greater variety of materials than the Egyptians, as some of their bridges were built of wood, some of stone, and some of chains and ropes.

The first bridge concerning which there is any definite information is an ancient Roman wooden bridge, the Pons Sublicius. This was built across the Tiber, about 600 B. C., and was a pile trestle. In these early days slaves and prisoners of war were the laborers, and construction was usually under the supervision of an army officer. In the construction of such bridges as those just mentioned human life was considered of little value, and the cost of labor was a small factor. Laborious methods of assembling the parts were used, and most of the heavy pieces

were moved by hand. The derrick is said to have been used at even this date, but it was little used on bridge work.

Since the time of Caesar wooden bridges have been built in large numbers. In England, as well as in America, there are some remarkable wooden structures. In Switzerland a wooden bridge was built with a clear span of three hundred sixty-six feet. On some of our American railroads and public highways, this material is still in use, especially in the West.

Stone was first used by the Chinese in the construction of the Great Wall, but we are indebted to the Romans for the greatest development of the stone arch, and for its first extensive application. Several old Roman arches are still standing as monuments to the skill and knowledge displayed by those early engineers. The problem of lifting the large stones, employed in the construction of these arches, was solved by the use of a crude form of derrick. This was in reality a long stationary lever arm, firmly anchored at one end. Other examples of the stone-arch construction exist in Germany and in France, but they are of comparatively modern construction.

The age of the use of stone for bridges of large spans is probably a thing of the past. Steel and concrete are the materials which are now used to the best advantage. Stone is too expensive to compete with these materials, both in regard to its first cost and its handling. Iron in the malleable state has been known from the earliest times, but it was not until the thirteenth century that steel was produced. Cast-steel was invented about five hundred years later.

Concrete is to-day extensively used in building and bridge construction. Many railroads use reinforced concrete in trestle work and in short-span girder construction. Highway bridges are being constructed of this material at the present time in large numbers, and it is safe to assume that it will soon be used in larger structures. The first extensive use of reinforced concrete was in France in 1887. In America no great progress was made until 1890 when Ransome constructed a reinforced-concrete arch and several notable reinforced-concrete buildings.

The first cast-iron bridge of which there is any record was built in England over the Severn, at Coalbrookdale, in 1779, by Messrs. Darby and Reynolds. Owing to the cheapness of timber iron was little used for bridges in the United States prior to 1850. The first iron bridge in this country was built over the Erie Canal in 1850. The advantages of iron over timber were soon recognized by bridge builders, and since 1850 steel bridge-construction has had a remarkable development. The early steel bridges were of the girder type, but this type was heavy and was not applicable to very long spans on account of the difficulty of placing such massive pieces of iron upon their supports. When the methods of determining stresses in a bridge were placed upon a firm mathematical basis (by Squire Whipple) the girder form of bridge gave way to a lighter type-the truss.

The engineers who had to solve the problems of steel-construction found their chief difficulty to be that of moving large and heavy members from place to place and from a position on land to that in the bridge. Large bodies of men were not

available, and methods had to be devised whereby large steel beams could be moved quickly and with the least expenditure of energy. The steam railroad soon provided a means of transportation to the bridge-site, and the problem developed into that of placing the members of a bridge in their respective positions. Timber was found to be a valuable aid, especially for use in the falsework of long spans. The old form of derrick was developed, and the traveller, with a crane or a derrick attached, has become an important factor in the construction of all large bridges.

In the early days the main object of the bridge was to provide an immediate and temporary means of transporting an army. The purpose to-day is to erect the bridge quickly and to provide a permanent structure. Often conditions of traffic are such that the passage of trains and vehicles cannot be stopped except for a very short time.

METHODS OF ERECTING STEEL GIRDER-BRIDGES

The plate girder type of bridge came into use soon after steel was used as a bridge-building material. Since that time the principles of design and construction have been developed to such a high degree of perfection that the girder is now used on spans which it was once thought impossible to cross by anything except a truss-or arch-bridge. The limiting span has been gradually increasing, and, although one hundred feet was once considered to be the maximum length for economic construction, examples will be cited of the erection of girders having considerably greater lengths. For spans up to one hundred feet the erection of a plate girder is a question of practicability rather than economy. In railroad work a fact to be considered is that traffic must not be interrupted for any considerable length of time while the bridge is being set into place. In regard to the ease of handling and erecting, the truss-bridge is considered to be the best type for lengths of spans greater than one hundred feet. Other factors to be considered, however, are length of natural life, cost of maintenance, and safety against derailments. In regard to these the girder is considered to be better than a truss-bridge of equal span.

The essential difference between a plate-girder and a truss-bridge in regard to erection is that the former is usually shipped from the shop to the bridge-site in such a form as to require very little work outside of placing it across the desired span; whereas the truss-bridge requires the assembling of many

parts.

The girder is now used to the greatest extent in railroad work, and several railroads are known to employ girders in preference to truss-bridges on comparatively long spans.

The problem of transporting plate girders by rail and over country roads to the bridge-site is an important factor in the erection of such a bridge and will be given considerable attention in this discussion. The loading, the transportion by rail, and the unloading of the heavy girders has often proved to be as difficult as the placing of the bridge in its final position on the abutments. To overcome these difficulties various methods have been developed by different builders and contractors.

The difficulty of erecting a plate-girder-bridge obviously increases with the span, and in this discussion the methods used in various bridges will be described in the order of increasing length of span.

Short-Span Girders

A short girder-bridge having a span of eighteen to twenty feet is usually shipped from the shop as a finished structure, with the exception of placing the ties and rails in a railroad bridge or the flooring in a highway bridge. If a railway bridge is to be built over a roadway a derrick is set up in the raadway, and the structure is lifted from the car, on which it was shipped, directly into place on the abutments. This is the simplest method known for handling girders, for the reason that they may be placed in their final position with very little adjustment. Instead of placing the derrick in the roadway it is

often placed on the embankment, and the bridge set into place from one end of the span. Another method often employed in the case of a short-span girder is to place a crane at the end of a platform-car and lift the structure into place. This is especially expeditious in the case of railroad girders, as the track is usually laid up to the opening before the building of the bridge.

When no one of the above methods is available or when the girder is too heavy to be lifted in the manner described, several other methods may be used. In the case of a new road the car on which the bridge is carried is run up to the opening, and timbers are placed in an inclined position leading from the car to the opposite opening. The bridge is then skidded into place on these beams, The final position is reached by removing the beams and allowing the bridge to settle on the abutments. The track is then laid.

If the girders and laterals are shipped separately the bridge is riveted together near the site, and is raised onto a dolly-car. The car is then moved up to the opening and the bridge is skidded into place, as before. This method is more economical amd almost as expeditious as the use of a derrick or a crane for spans up to about twenty-five feet. The same method is employed where the girder is to replace an old span, with the exception that the girders are skidded separately, one on each side of the old bridge. They are then moved laterally into place under the track and the old bridge removed without any interruption of traffic.

Medium-Span Girders

An interesting method of erection and one that is often used, in principle at least, was that used in the erection of a bridge composed of four, ninety-five-foot spans at Wabash, Indiana. The transporting of these girders by rail and over the gravel roads illustrates the methods employed in handling heavy girders. The girders were built in the shops, were fastened in pairs by a bracing of six by eight-inch oak timbers and iron clamps, and were hoisted onto the cars by a combination of an air hoist and a stack of cribbing on each side of the track. When placed in position on the cars the girders rested on four timbers placed on the two end cars of a string of three cars. Little weight was borne by the middle car. Very little trouble was experienced on the trip by rail, but in moving the girders to the bridge-site, three-quarters of a mile from the road, special methods had to be used. Jacks were placed under the girders and the girders were raised to a sufficient height to permit the placing of two pairs of trucks under the center of the members. The girders were then removed from the car and the trucks allowed to move on heavy plank placed on the gravel road. A hoisting engine was set on a platform near the end of the girders; and by means of snatch-block and tackle, fastened to telephone poles, the girders were hauled to the bridge-site. One girder might have been hauled alone by means of horse power, but the danger of upsetting would then have been an important factor. The girder reached the bridge-site with the forward end projecting over the abutments, and in this

position was used in hoisting into position the first bent of the falsework. Only two bents were used for each span and the floor-beams were placed upon these to act as a track for the girder itself. The first set of floorbeams was clamped, and a track of two-inch maple plank was laid for the truck wheels. When the forward end of the girder had been hauled over the end of the second set of floor-beams, the girders were in a position to be lowered onto the masonry. They were first blocked up and later the trucks were removed, and the girders were lowered onto steel beams sliding on greased plates on the masonry abutments. The members of the first span were then unclamped and spread apart into their final positions. The floor-beams were then swung into position by a derrick and riveted. Joists were next placed on the floor-beams and the track laid so that the girders of the second span could be run out. These girders were moved out until their ends protruded slightly, and the second span was then erected in the same manner. Each of the five spans were erected in this manner, and the average time taken to run out a girder and place it in position was ten hours.

Long-Span Girders

An example of the erection of a plate girder of extreme length is that built across Yankee River at Hubbard, Ohio, by the Erie Railroad. The length of the span was one hundred thirty-one feet, four inches; the height was nine feet, six inches, and the distance, center to center of girders, was six feet. This is one of the longest girders ever built, and as it

replaced an old truss-bridge, it was found necessary to raise the grade of the old bridge three feet to permit the use of a deck girder.

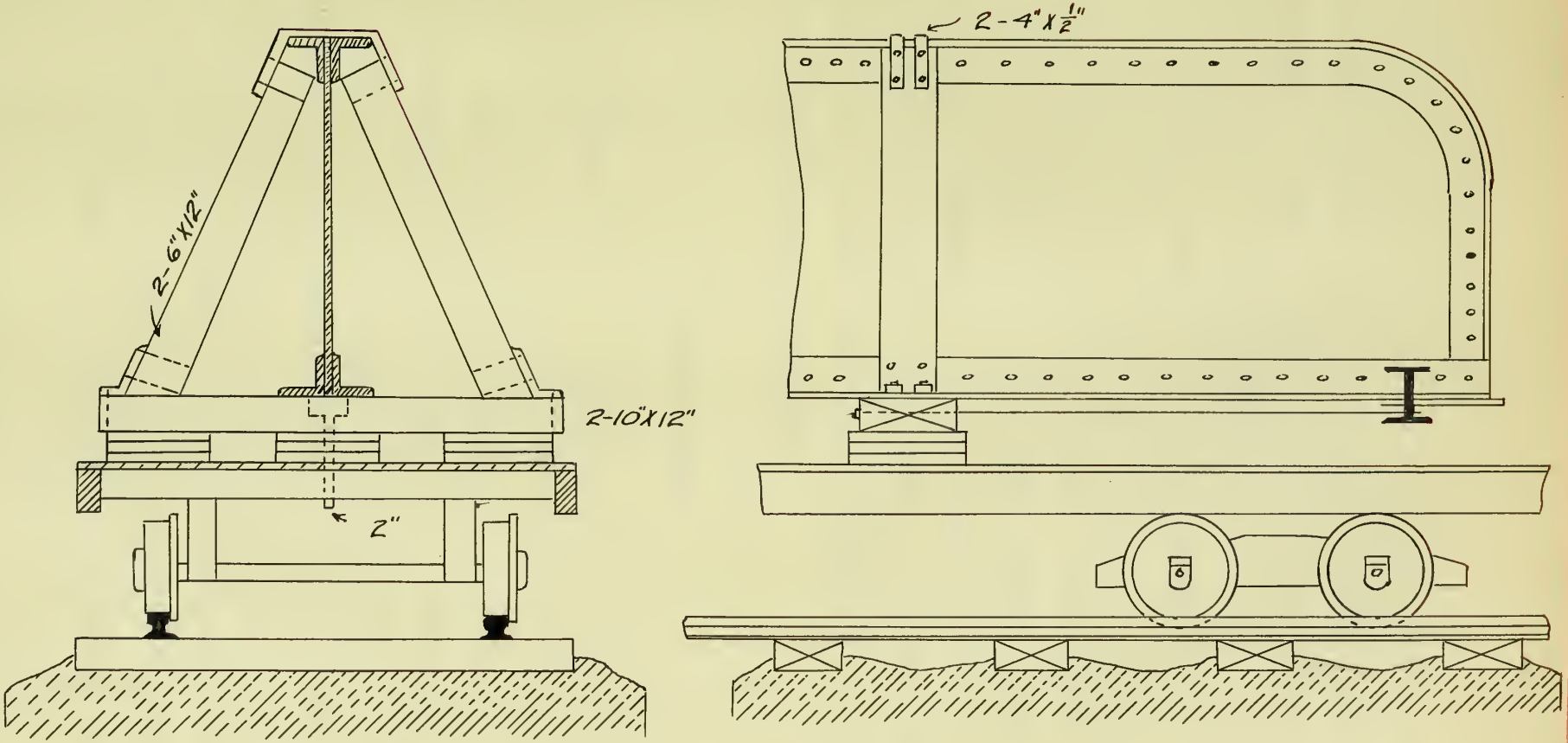
The two girders were delivered to the Erie Railroad at Elmira, New York, and the road undertook the transportation and erection of the bridge. The girders were placed on the cars singly, the load being carried by the two end cars of a series of four. The intermediate cars had bracing, which was to be used in case of emergency. The girder was braced in an upright position by diagonal wood-stints, composed of six by eight-inch timbers clamped to the transverse timbers underneath, thus forming a cradle. It was necessary to run the train at the slow speed of four miles per hour for a part of the distance.

At the site a crib-work was erected for a length equal to that of the car, and the cars bearing the girders were pulled up alongside. Beams, capped with rails, were laid across the opening between the car and the crib-work, and the girders were skidded onto the temporary structure. The rails were well lubricated with machine oil and a pile-driving engine was used to pull the girder across the opening. The girders were skidded onto the cribbing separately. After the second girder was placed on the cribbing, the laterals, the sway bracing, and the cross-frames were put in place and riveted. The ties and rails were then placed in their proper positions so that the bridge would be ready to receive traffic as soon as it was in place.

A trestle was next built across the river in a line with the cribbing and a downward grade of four per cent provided

for sliding the bridge down it. Two lines of rails, nine feet apart, having two rails to a line, were placed on which to slide the bridge. Skates, composed of seven-inch channels, were then placed on the bottom of the girders. Machine oil was again used as a lubricant, and the structure was hauled down ready to be skidded laterally into place. The old bridge was then skidded off to a temporary trestle and the old abutments raised to a proper grade. The new bridge was placed in position laterally by means of four lines of rails, placed over the abutments at the ends of the span. The shoes were next put into place, and the bridge placed in its final position. See Plate I.

PLATE I



METHOD OF LOADING LONG GIRDERS.

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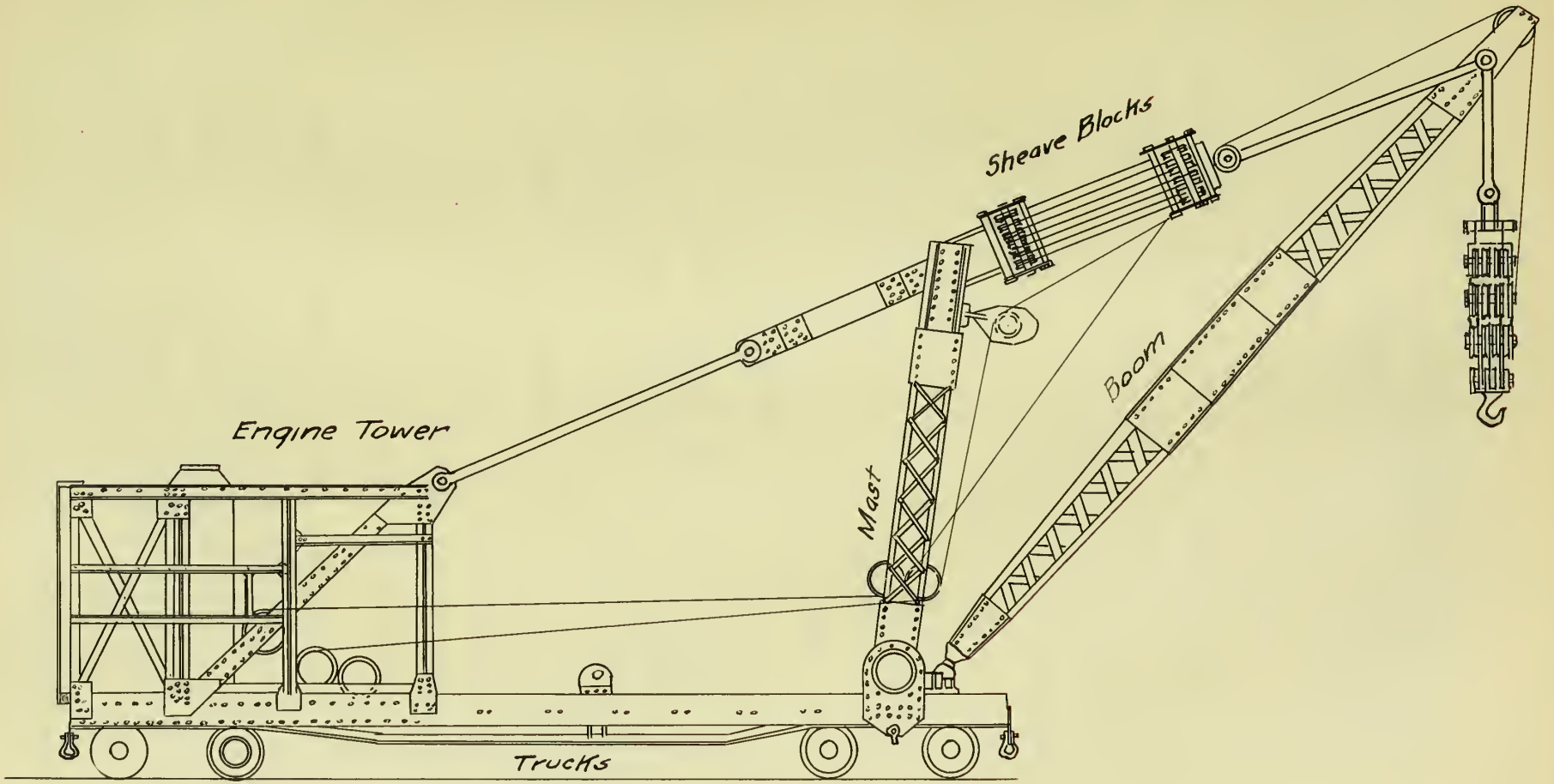
In connection with the erection of plate girders the derrick-car was mentioned and was shown to be an important factor in the erection of such a bridge. It is of even greater importance in the erection of truss-spans, both large and small, and is being improved and used by many bridge builders in preference to the traveller. Its chief use is on railroad bridges where the necessary track is already in place. The traveller is often employed with the derrick on large jobs. Before taking up the description of the methods used in the erection of truss-bridges a typical example of each of these forms of erection apparatus will be described in order that their function in the erection of bridges may be clearly understood.

The Derrick-Car

Derrick-cars are of varying sizes, depending upon the size of the work and the weight of the pieces to be lifted and moved about. The thirty-ton car used by the Chicago, Milwaukee, and St. Paul Railroad is a good example of a derrick car. (See Plate II). Larger cars are a little more complex in regard to the different parts than smaller ones, but the general form is much the same. The features of this thirty-ton car are a fifteen-foot mast, a thirty-foot boom, and $2\frac{1}{4}$x$2\frac{1}{4}$-inch steel bars used for backstay. These parts, together with a thirty-horse power engine and rigging are mounted on a fifty-foot flat-car of heavy construction.

The fundamental requirements of a derrick-car are; a

PLATE II



CHICAGO, MILWAUKEE AND ST. PAUL 30-TON STEEL DERRICK CAR.

considerable length of boom-reach, together with the necessary stability of the car, a strength of the various parts sufficient to withstand the stresses produced by heavy loads, and a weight which is not too great to interfere with convenient transportation. In considering these requirements an important part to be noted is that the number of uses to which a car can be put varies in proportion to the length of the boom. The longer the boom and the greater its capacity, the greater must be the longitudinal and lateral stability of the car. The necessary longitudinal stability is easily obtained by increasing the length of the car and by adding a counter-weight to the engine and rigging. Lateral stability is much more difficult to obtain than longitudinal stability because the width of car available against overturning is limited to the distance center to center of rails, unless outriggers or grips are used. Lifts which are placed at a great distance from the center line of the track are obviously limited by lateral stability. The height of the tower is made as great as possible to reduce the stresses in the boom and in the tackle. This height is limited, however, by the considerations of traffic, such as overhead wires, and clear head-room in through bridges, both during transit and when at work. The upper part of the derrick-car consists of an A-frame which is removable in transit. The booms are made in sections, and it is thus possible to have lengths of thirty,fifty, sixty-five, and eighty-five feet on the thirty-ton car.

When heavy loads are being lifted provision is made for

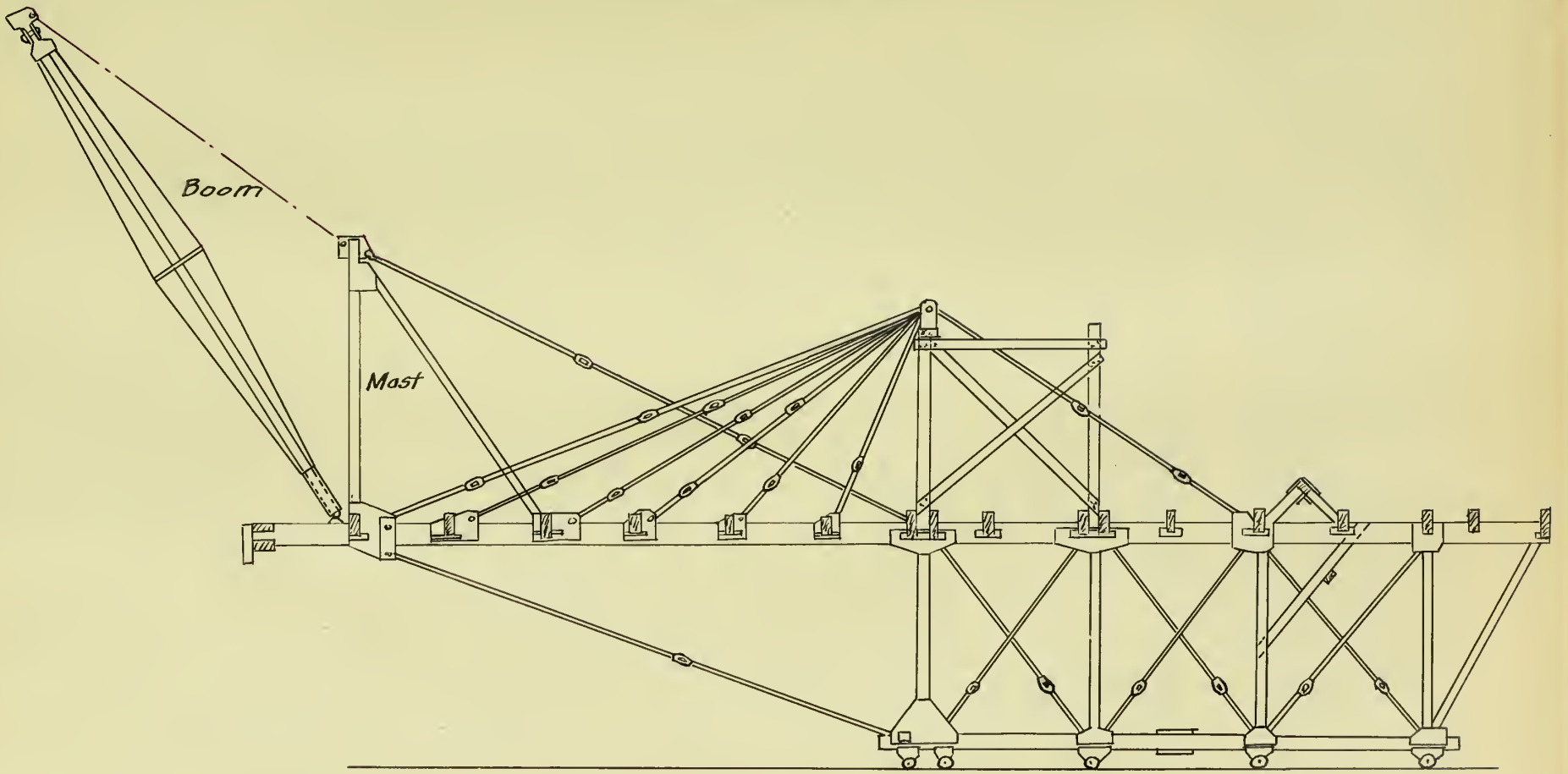
relieving the load which comes on the side bearings and springs. This is accomplished by the insertion of heavy blocks of wood between the body bolster of the car and the frame of the trucks, thus transmitting a large part of the load directly to the trucks. One of the characteristics common to the different makes of derrick-cars is that all shafts, together with all gear wheels attached to the same, are caused to revolve whenever steam is admitted to the engine cylinder. The drums run loose on the shafts and can be made to revolve with the shaft by friction-clutches. When the clutch is disengaged, the drum can be held without motion by means of the brake. In the meantime the shaft revolves and operates the other lines. With one hundred ten pounds of steam pressure the engine is able to exert an eight thousand-pound pull. It is necessary to have three men in the cab; one to control the throttle and two friction drums, one to operate the two swinging lines, and a third to operate the runner lines. The car is self-propelling.

The Traveller

The traveller is a form of apparatus which must be designed to meet the local conditions found at any particular bridge. It is usually designed by the engineer in charge of construction, and is erected on the falsework of the bridge. The traveller runs back and forth on stringers laid on the falsework and spaced sufficiently far apart to enable the traveller to span the steel trusses. Usually travellers are made of wood and consist of two, three, or four bents, laced together. At the foot of the posts are placed single wheels or trucks which run on the stringers.

A form of traveller employed by the Chicago, Milwaukee and St Paul Railroad on a large part of its work will be described in detail. (See Plate III). It consists of a wood and iron structure of three panels at twenty feet each, which spans the railroad track at a height above the rails of twenty-five feet, which is sufficient to give clearance to the trains. At the front end of the traveller is a cantilever arm, seventy-five feet long, to which are attached two wooden beams, giving a total reach of about one hundred twenty feet. The cantilever is equipped with four trolleys, each of fifteen tons capacity. Each trolley is composed of steel carriages on rollers, from which are suspended two four-sheave blocks. A ten-ton hook is swung from each boom and thirty tons of rails are placed at the rear end of the traveller to act as counterweight. Additional anchorage is obtained by

PLATE III

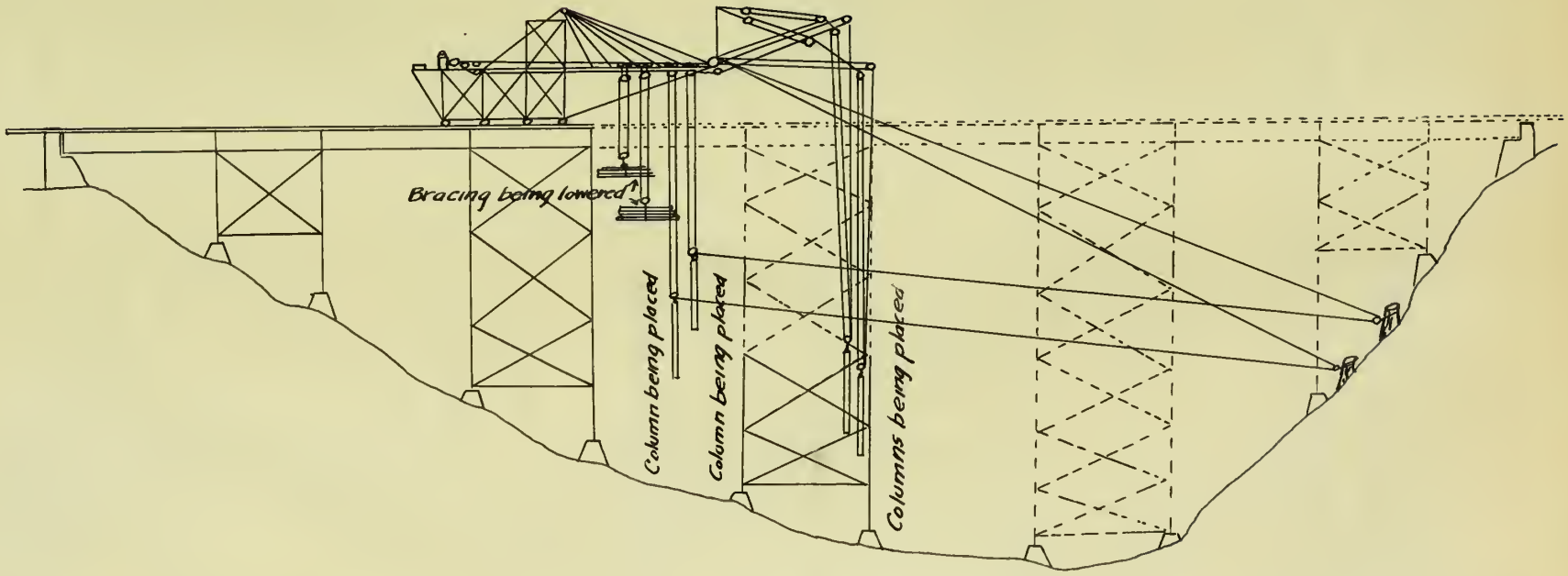


CHICAGO, MILWAUKEE AND ST. PAUL WOODEN TRAVELLER.

fastening the traveller to the girder or track on which it runs, by means of hooks. Hoisting cable-guys are attached to the top of the traveller and to the falsework at the side to furnish side-way anchorage. The engines employed are similar to the one used on the derrick-car.

The operation of the traveller is somewhat complex and requires a crew of thirteen men. The ten-ton hook at the end of the boom is suspended from a four-part tackle and is operated by means of a fall-line, through an idler sheave at the end of the boom, thence through a snatch-block at the foot of the mast, and thence to the lower drum of the hoisting engine. The engineer operates this line. The boom is raised and lowered by means of a seven-part tackle, connected in a similar manner to the upper drum on the engine. This is also operated by the engineer. The boom is swung laterally by a five-part tackle, connected by a fall-line to the outside winch-head on the engine. Each one of the fifteen-ton trolley-hooks is operated by a fall-line through a series of snatch-blocks and back to the inside winch-head of the engine. This fall-line is also used for traversing the trolley. Six men are employed in handling lines on one side of the traveller, two of whom are available for handling signals, and a third man, with the assistance of these two, transmits all signals to the engineer. See Plate IV for a sketch showing a traveller at work erecting a viaduct.

PLATE IV



DIAGRAM

SHOWING TRAVELLER PLACING MEMBERS OF A VIADUCT

The methods used in the erection of truss-bridges will now be described, and, as has been previously stated, this description will be divided into two parts, namely; methods used on small truss-bridges, and methods used on large truss-bridges.

METHODS OF ERECTING SMALL TRUSS-BRIDGES

Short-span truss-bridges, or bridges with a clear span of one hundred fifty feet or less, are erected by a variety of methods, some of which closely resemble those used on large truss-bridges. Other methods resemble those used in the erection of plate-girder-bridges. The method to be used is governed by local conditions and by the form of the truss. As a large proportion of the short-span bridges are built by railroads, the methods employed by them will be given considerable attention in this discussion.

The derrick-car and the traveller are the two forms of apparatus which are used in the construction of practically all short-span bridges. When the derrick-car is available it is used in preference to the traveller. The reasons for this are that the cost of additional falsework required by the traveller and the the cost of erection of the traveller more than compensate for any advantage which it may have over the derrick-car. Derrick-cars are also prefered for handling the material.

The present practice among the railroads is to make all truss-bridges, up to a span of one hundred fifty feet, riveted

structures rather than pin-connected ones. The principal factors in the design of such a bridge are the impact and the traction forces, and a riveted truss, being more rigid, offers better resistance to these forces.

Under the ordinary conditions met during erection, falsework is used for short truss-spans. This falsework usually consists of simple pile bents with eight-by sixteen-inch timbers, resting on the caps. The top of the timbers should be eight or ten inches lower than the bottom flange of the new floor beam, and the bents should be driven as close as possible to the old floorbeams. In case the new bridge does not replace an old structure the pile bents should be driven directly under the new floorbeams. In tearing out an old bridge preparation should be made so that traffic is stopped as short a time as possible. The old stringers should be shifted so as to rest upon the falsework and not upon the old floorbeams.

In assembling the new bridge the first operation is to set the bases on the abutments. The lower chords of the trusses are then put in position, and are supported at the splices by blocking, which rests on the falsework. The assembling of the members is done by means of a derrick-car. After the lower chord is set in place the next step is to assemble the floor system and this is done between trains, one part at a time, or all at one time, as the period between trains permits. The old track is first torn out and the new floor-beams and stringers are set in place. On top of these are laid the ties, and the new track is

then laid as fast as possible,so that the derrick can move forward. The trusses are next erected. A vertical post at one end is erected, and following this the end-post and web members are set in place, the work on both trusses being carried forward simultaneously. Riveting is commenced as soon as the erection of the trusses permits and is carried on during the erection of the trusses. The upper chord members are the last to be placed and this requires more time than any previous operation. Generally, the first section includes three panel lengths and it must therefore fit the web members of the three panels simultaneously. A mistake in the level of the lower chord will thus affect the upper chord. The portals and upper lateral system are the last to be set in place.

Riveting is an important part of the erection of a bridge, and, as has been previously stated, is commenced as soon as the erection permits. Two methods of riveting are used; hand-riveting and compressed-air-riveting. On small jobs the cost of the two is practically the same, but on large jobs compressed-air-riveting is more economical. Air-driven rivets are better than those driven by hand, because the rapid blows of the hammer upset the rivets in the hole better than the slow hand blows of the man. Compressed-air-riveting is especially advantageous on light truss-bridges where conditions will not permit easy hand-driving. Four men compose a riveting squad.

The Cantilever Method of Erection

A method frequently employed in the erection of short-

span truss-bridges, when conditions will not permit the erection of falsework, is the cantilever method of erection. An example of a short-span bridge built by this method will now be described.

The cantilever method of erecting bridges is well illustrated by the erection of a bridge across the Potomac River at Cumberland, Maryland (See Plate V). The river at this point had a very swift current, and therefore the erection of falsework was impracticable. The bridge, as designed, consisted of three deck-spans of one hundred fifty feet each, with riveted trusses, twenty-five feet deep, which had a clearance of forty feet at low water. It was found that the members of the trusses were heavy enough to withstand the additional stresses produced by the cantilever action.

The materials of construction were delivered on canal boats, and were unloaded along the axis of the bridge, one hundred fifty feet east of the east pier, by a standard ten-ton derrick having a fifty-six-foot boom. The derrick was placed on the substructure on the channel bank just clear of the tow path, and was also used in erecting three bents of the falsework on the shore. On these bents a traveller was erected which completed the erection of the falsework to the first bridge-pier. The third span was erected on this falsework, having all field connections filled with fitting-up bolts. This increase in weight added materially to the anchorage required for the erection of the next span by the cantilever method. Adjustment of the parts was also facilitated by the arrangement of bolts. The erection

PLATE V

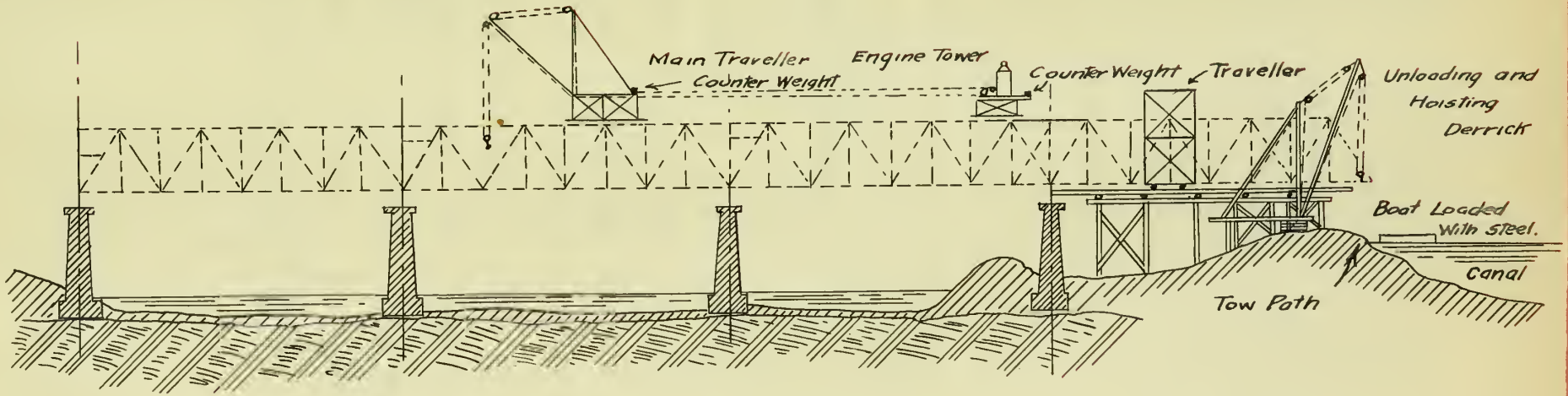


DIAGRAM OF INDEPENDENT SPANS AND ANCHOR SPAN AND TRAVELLERS FOR CANTILEVER ERECTION.

22-B

of the second span was accomplished by means of the traveller, previously mentioned, which operated in the usual manner, receiving material from a flat-car, which ran on a narrow-gauge track. The parts first assembled were stringer, the ties, and the kicking-blocks at the end of the bottom chord. Two panel lengths of the lower chord were next set in place and were temporarily supported by special erection ties. The hip-vertical was then set in place, and the panel thus became self-supporting. The traveller then moved forward two panel lengths, and the erection was completed up to the next pier in a similar manner. When the pier was reached the span was permanently seated on it, and a counter-weight was placed at the end of the span first erected, and the erection proceeded as before.

When in service the traveller was clamped to the superstructure at the foot of each post, and an advance was never made until all the horizontal transverse bracing was assembled up to the point at which the truss erection was to be continued. Two-thirds of all the open holes were filled with fitting-up bolts at the completion of the erection, and these were replaced by field-driven rivets as soon as the trusses were swung into their final positions. The erection of these three spans demonstrated the possibility of erecting free riveted trusses by the cantilever method.

Methods of Erecting Very Short-Span Truss-Bridge

In addition to the two methods of erecting short-span truss-bridges, just described, there are several other methods employed on very short spans which should be mentioned. Frequently the trusses for a bridge are assembled at the bridge shop and are shipped to the bridge-site on flat-cars. At the site there are two methods in use for placing the bridge in its final position on the abutments, and the method to be used depends upon the condition that an old bridge does or does not have to be removed. In the former case the trusses are lifted separately from the car and set in position just outside of the trusses of the old bridge. Next, the floor system of the old bridge is arranged so as to be supported on the new trusses. When this is done the old trusses are removed and the new ones slid laterally into their permanent position. The lateral systems and floor system are next set in place.

If the bridge is a highway structure over which traffic may be suspended for some time, the old structure should be completely removed before attempting to place the new one on the abutments. The derrick-car would not be available for the construction of most highway bridges by this method, and it would be necessary to erect a derrick near the bridge opening. Another form of apparatus frequently used in connection with the erection of small bridges is the gin-pole. This is a long pole, constructed of solid material, and rests, securely fastened, on

a firm foundation. It is held in a vertical position and is guided by guy-lines or wires, attached both to the top of the pole and to the ground at some distance away. At the top of the pole is an arrangement of block and tackle, by means of which loads are lifted. In some cases the use of this apparatus is more expeditious than the use of the derrick-car.

When the bridge is to span an opening which is not spanned by an old bridge a method is used which will be briefly described. The trusses are assembled at the shop and are shipped to the bridge-site, and the bridge is erected on the shore near the opening. A derrick-car is placed at the bridge opening, and the entire structure is raised and placed in its position on the abutments. This method is obviously not applicable to the erection of a bridge having any great length of span, as too much lateral stability is required of the derrick-car. The limiting span-length for a method such as the one just described is about eighty or ninety feet.

A bridge built across the Tennessee River, near Florence Alabama, is a good example of such a structure erected by a peculiar method, yet one which has often been employed. The bridge is a structure of twelve spans of one hundred fifteen feet each, and was built to replace an old wooden truss-bridge. No interruption of traffic was allowed, and it was decided to build the new bridge directly above the old one and then lower it into place, span by span, after the old bridge had been lowered out of the way. The old structure was not strong enough to carry the new one, and therefore a traveller span, moving forward after the completion

of each span, was used to temporarily support the new structure. This travelling span consisted of two wooden Howe-trusses, each one hundred fifty feet long. The hip-verticals were supported on rolling towers, twenty feet high, which had four double-flange wheels, tandem on each rail of the sixteen-foot-gauge track which was laid on top of the upper chord of the old truss.

The bridge was erected in the following manner: The top chords of the new span were suspended by adjustable connections from the bottom chords of the traveller spans, and the other members were next connected to the top chord and to each other, so that eventually the whole structure was suspended from the travelling span. The weight of the new span was partially transferred to the piers by 12x12-inch vertical posts, wedged under the bottom chord of both ends of the traveller. The operations of lowering the old span out of the way and lowering the new span into place were carried on simultaneously. The top chord of the old span was connected to the bottom chord of the new one, the end panel members were removed from the old trusses, and the new bridge was then lowered onto the pedestals which had been erected on the masonry. When it reached this position the old truss rested below the bridge and out of the way. Later the old truss was taken apart and removed.

METHODS OF ERECTING LARGE TRUSS-BRIDGES

In passing from a description of the methods used in erecting small truss-bridges to those used in erecting large truss-bridges it should be noted that the traveller now becomes the most important of all apparatus used in erection. Several methods of erection, which were used on large truss-bridges will be described, and in nearly all of these the traveller is an important factor.

The McKinley Bridge at St. Louis, Mo.

The McKinley Bridge, which spans the Mississippi River, is the largest and most important bridge ever built for electric interurban traffic. It is designed to carry highway as well as interurban traffic. Work was started on the substructure in 1907, and the bridge was completed in October, 1910. The main chanel of the river is fifteen hundred feet wide between government harbor lines, and is crossed by three main spans, each five hundred seventeen feet long, center to center of piers. On the Missouri side are three deck-truss spans each one two hundred fifty feet long, and two spans, one hundred fifty feet each. On the Illinois side are two deck-trusses, one two hundred fifty feet long and the other one hundred fifty feet long. There are long viaduct approaches on each side. The deck spans are pin-connected trusses with the fixed ends resting in a recess in the pier which carries the channel span. The methods and the plant used in the erection of this bridge are of considerable interest.

The main storage yards for the steel work were at the

west side of the river, along the bridge approach, between the C. B. and Q. tracks and those of the Merchant's Bridge Terminal Line. This area was traversed by three unloading tracks. Between these tracks were placed two twenty-ton derricks, each of which had a sixty-foot boom and a sixty-five-foot mast. A feature of this derrick was the mast and boom seats, which were formed in a single casting. The arrangement of the block and tackle was similar to that previously described in the C. M. and St. P. derrick. A third derrick was arranged for use in hoisting steel to the viaduct, from which it could be transferred, by means of cars, to its place in the structure. The capacity of this derrick was forty tons, which was sufficient for the heaviest piece of metal on the bridge. The steel derrick was erected at the bridge-site by means of a gin-pole, resting on blocking on piles. The gin-pole itself was guyed with cables,fastened to an eighteen-inch pile head, three hundred feet distant from the blocking. The engine in the large derrick was capable of developing thirty horse-power. In addition to the derricks mentioned, a light derrick-car was used for small pieces.

The forty-ton derricks were used in erecting the three spans of the approach viaduct. The long girders used on this viaduct were placed on trucks, and were carried directly beneath their final position on the C. B. and Q. tracks. A gin-pole was erected at the west side of the track to construct a gallows-frame. This frame was used to erect the post which supported the girder bearing and was also to erect the first bent of the traveller on the east side of the tracks. After the second bent had been

erected and the posts and the cross-girder for the last support of the span had been placed in position the girder was raised and laid in its final position on the bearings. A ten-ton derrick was next erected on the viaduct, and work was begun in both directions, a traveller being used on the deck-truss-span opposite. The width of the traveller was sixty-five feet at the top, and thirty at the bottom. Its height was seventy-five feet.

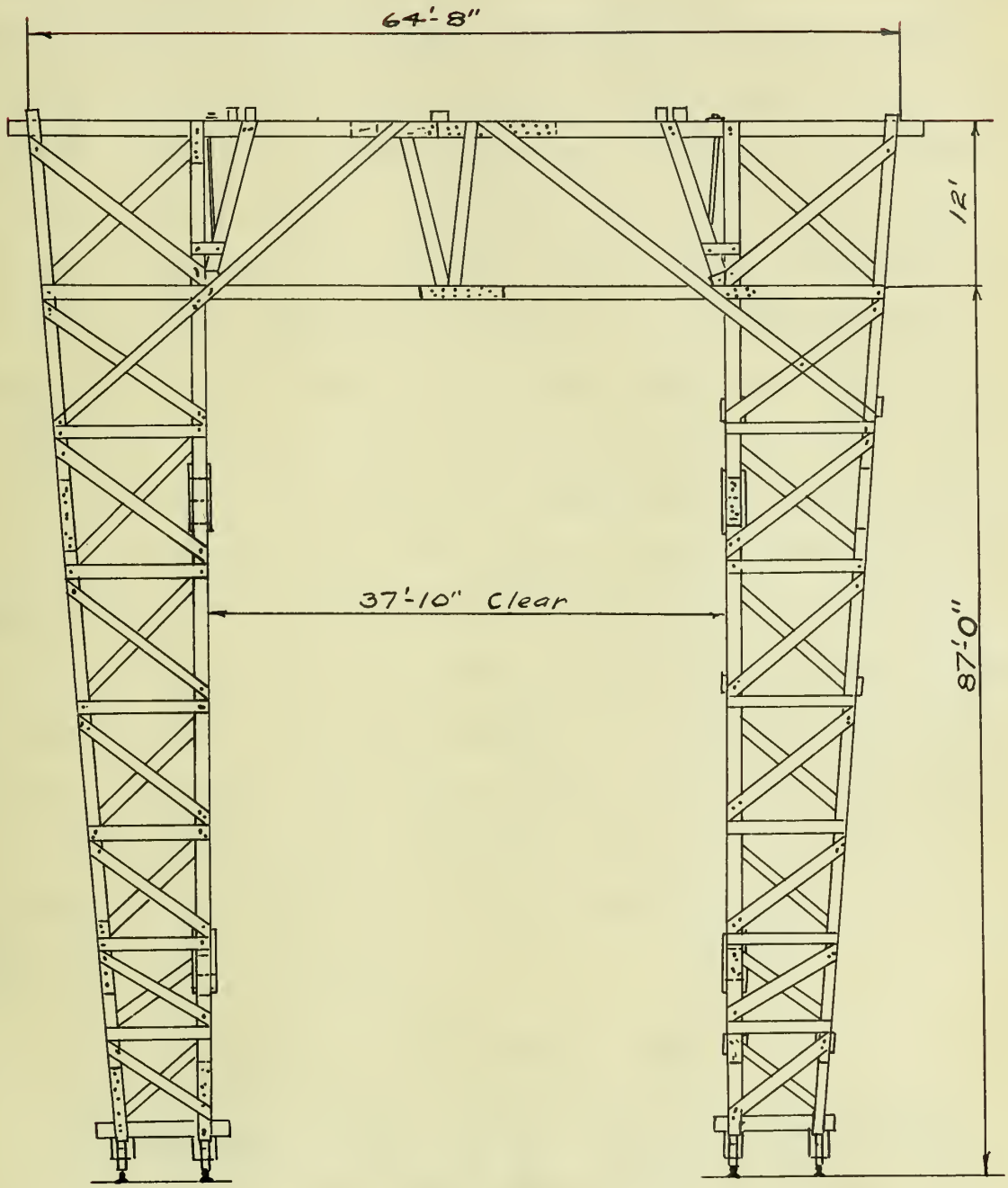
The falsework for the one hundred fifty-foot span consisted of one-story frame bents, resting on cribbing, which in turn rested on piling. Six piles were used as a foundation for each bent. 12x12-inch posts were used for the bents with 3x10-inch cross-bracing. Lines of 12x12-inch timbers were run out on the pile caps and 6x16-inch timbers were laid transversely for the support of the traveller rails and trusses. At the end of the first span a pony bent was erected and a flooring was built on this to enable a derrick to lower material to the top of a push-car, which in turn transfers it to the traveller. The falsework for the two hundred fifty-foot spans was also composed of one-story frame bents, resting on piles cut off at the grade of the curved bottom line of the trusses. It was first proposed to use jacks and to raise and lower the traveller so that it would be at the elevation of the lowest joint on the bottom chord, but this method required a considerable amount of blocking and was dispensed with. The final decision was to support the traveller in the same manner as in the short spans. The end bearings were placed in niches in the abutments, and this required a careful

assembling of the parts and the placing of the shoes before proceeding with construction of the span. Temporary bracing was used to support the trusses during that part of the erection prior to the placing of the floor system.

The falsework for the first long span was supported on foundation piles, which were cut off twenty feet below the surface at low water. The piles were forty to sixty feet long, and the average depth to which they were driven was twenty feet. The falsework was constructed in bents of three stories each. The erection of this falsework was accomplished by means of a ten-ton mule-traveller. The different stories were placed on barges, and were then raised to their final positions by the traveller.

A large three-bent traveller, ninety-nine-feet high, was used in the erection of the three large spans. (See Plate VI). The method used in the erection of the traveller was interesting. The falsework was erected at a distance from the main pier equal to the height of the traveller, and the first bent of the traveller was then bolted together while lying flat on the falsework. A trip-bent was next erected in a vertical position with its base resting on the base of the traveller. This was connected to the main bent by two inclined timbers, fastened to the top of the former and midway on the latter. A hoisting cable was run through sheave-blocks, which was attached to the main bent, the trip-bent and the steel structure, west of the pier. From this latter block the cable was extended to a hoisting engine one hundred twenty-five feet from the main bent. By means of this cable the main

PLATE VI



WOODEN TRAVELLER
USED ON
THE McKINLEY BRIDGE AT ST. LOUIS MO.

bent was raised to a vertical position. The second and third bents were bolted in a similar position, and were raised by lines running through the first bent. Steel was delivered to the traveller by flat-cars, operated by a light locomotive. The traveller was run out to the center of the span, and the erection was begun at this point. The panels were completed, for one-third of the distance to the end, and the bottom chord and web members were then completed from this point to the end of the span. The chord was then set in place. When this was done the operation was resumed at the center, and the bridge was completed to the other end of the span. Two twenty-ton hoisting gibs were used in raising each top chord section, and a wooden float was raised between the trusses for the use of the men engaged in riveting. The last operation was the placing of the lateral systems and floor system. When this was done the falsework was removed and placed in the second span, and the erection of that span was completed in the manner just described. This method is typical of that used in the erection of bridges across an opening which will permit the use of falsework.

Erection of the Quebec Bridge

The Quebec Bridge, as first designed and partially erected, consisted of two five hundred-foot anchor spans and one eighteen hundred-foot cantilever span. The distance between shore piers was twenty-eight hundred feet on centers. The weights of the anchor arms, cantilever arms, and suspended span were respectively 12,500,000, 15,000,000, and 6, 000,000 pounds. Among the

largest and heaviest members to be handled and erected by the traveller, at great height, were the 4½x5½-foot lower chord pieces. These were sixty-eight feet long and weighed about one hundred tons each. Some of the pieces to be handled, when placed on ordinary cars, were too wide and too high to clear the tunnels and bridges along the route, and their weight was also too great for these cars. Consequently special steel cars were designed by the railroad company. None of the pieces was assembled at the shops, complete reliance being placed on the accuracy of the design, the workmanship, and the inspection. Pneumatic hammers were used in driving the five hundred thousand field rivets used on the bridge.

The superstructure of the bridge was erected by the usual cantilever method, i.e., the anchor spans were erected on falsework and the cantilever arms were then built extending out over the river and connecting to these spans. The plan of erection was to build the south anchor arm, the south cantilever arm, and the south one-half of the suspended span first, and the north one-half of the bridge last. The falsework and the traveller used on the south half was to be transferred to the opposite side and used in the erection of that portion as soon as the south half of the bridge was completed. However, the collapse of the bridge while work was in progress on the south cantilever arm prevented the carrying out of this plan.

The methods used in handling and storing the steel work, the use of steel falsework, and the design of the traveller were interesting features of the erection of this structure. Other

features were the elimination of steam as a source of power, and the use of electricity in its place for the hoisting machinery and for the lighting system.

The materials of construction were delivered by rail to the yards on both sides of the river, each one of which was equipped with two sixty-ton, sixty-eight-foot girder-cranes, having clearances of thirty feet. These cranes travelled on a seven hundred fifty-foot run-way, consisting of plate girders which were supported on four-post trestle bents. Electric motors furnished the motive and hoisting power for the crane. The space between the trestles was covered with 12x12-inch transverse skids, supported on 12x12-inch longitudinal sills, which were spaced three feet apart on center. On the top of the skids were spiked light steel rails, to facilitate the sliding of the heavy members which were piled on them. Between the runway girders were two standard-gauge surface tracks. One of these was used to receive the railroad cars, laden with material, and the other was for use in transporting this material to the traveller.

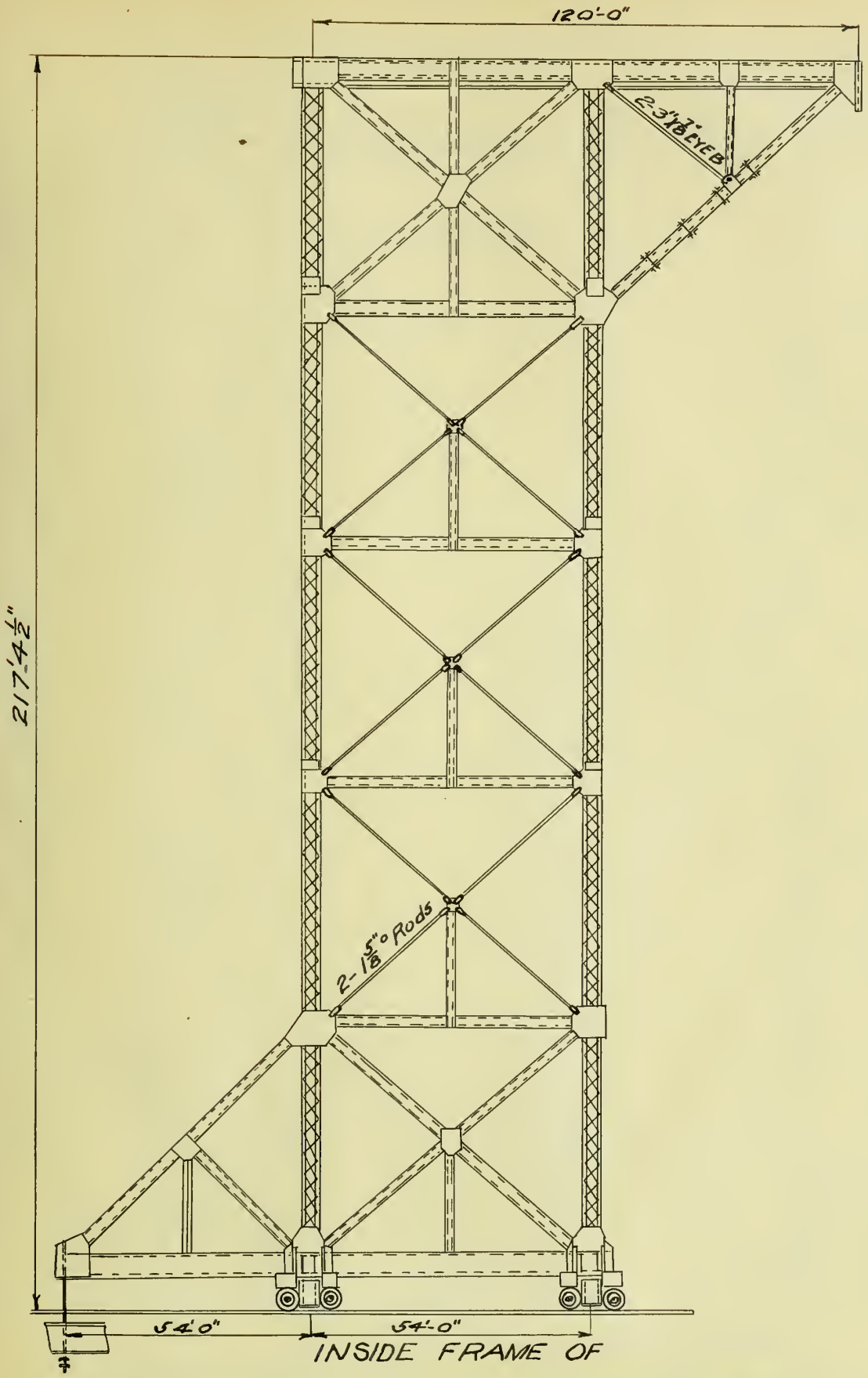
The anchor spans, each five hundred feet long, were erected on shore on steel falsework. The falsework, which was a feature of this method of erection, consisted of eighteen 9x9-inch towers, varying from one hundred twenty-seven to one hundred sixty feet in height, the towers being placed at the panel points of the anchor spans. Each pair was braced to form transverse bents. Longitudinal bracing, consisting of horizontal struts and diagonals, divided the structure into four towers. The vertical posts of

these towers were laced together with angles, and each pair was seated on a transverse plate-girder sill. The two girder sills for each tower were seated on 17x17-inch grillages, with three solid courses of timber underneath to transmit the pressure to the soil. The two outside posts of each tower were carried several feet above the tops of the inside posts to help support the two twelve-foot traveller tracks. The traveller track-stringers were taken from the main structure, fifteen panel lengths of them being used. They were taken up from the rear and were placed in front of the traveller as it advanced. A change in the height of the falsework were made by alterations in the lower sections of the vertical posts. The steel was delivered to the traveller on two standard-gauge tracks at about the level of the permanent bridge-track. A wooden falsework, which was independent of the steel falsework, was used to support the temporary tracks.

After the falsework for the south shore anchor span was completed, the same wooden traveller was used for the erection of a two hundred twelve-foot steel traveller, which was to be used on the cantilever arms.(See Plate VII and Plate VIII). The lower part of this traveller was erected by the wooden traveller, the remaining part being completed by the use of gin-poles and derrick-booms. This steel traveller was designed to erect all of the steel in the long span and to swing and support heavy members at a distance far beyond the support of its own base.

Work on the south cantilever arm was begun with the forward bent of the traveller in the place of the first vertical post. The first panel of this arm was erected in thirty-seven movements

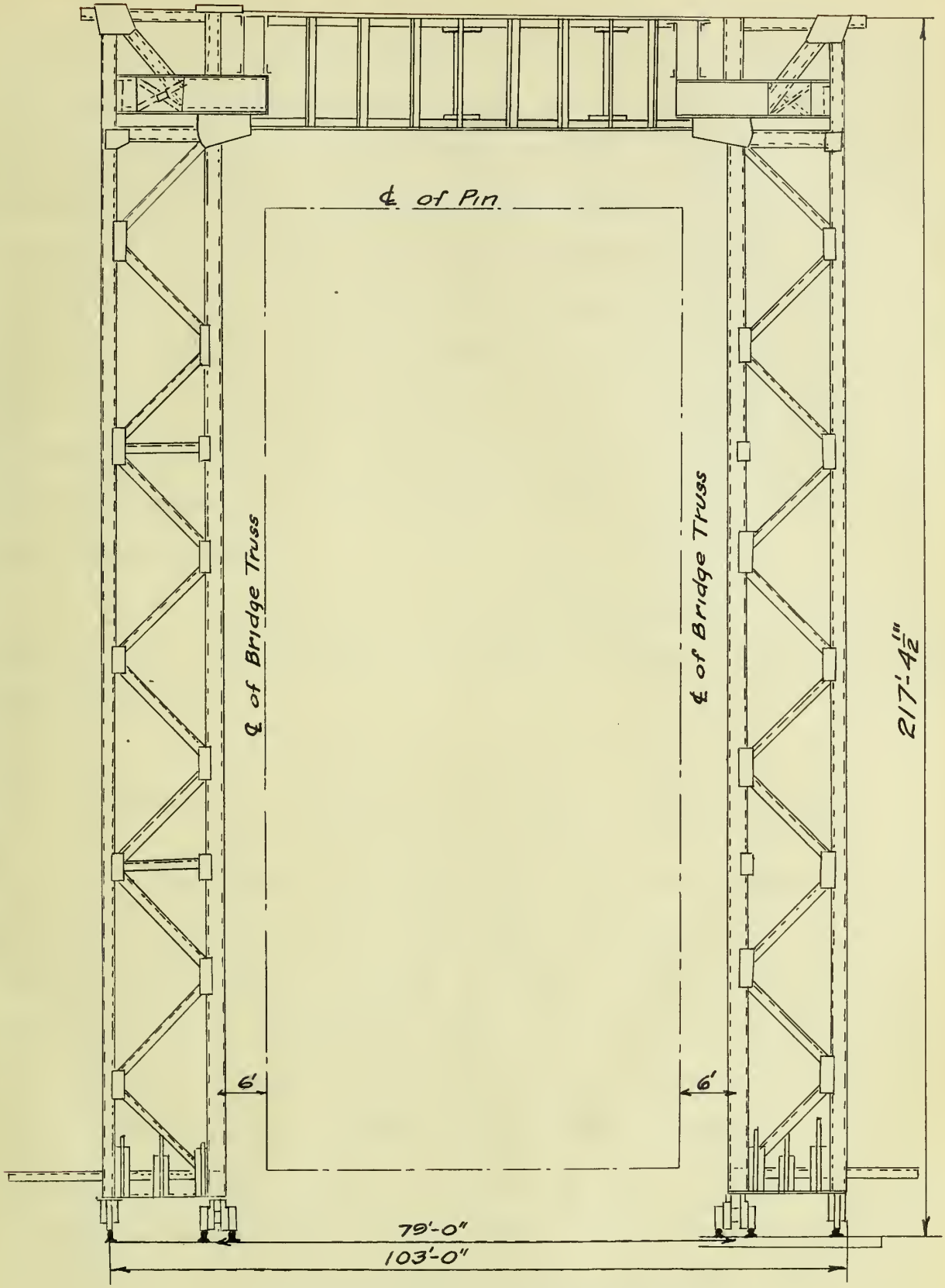
PLATE VII



INSIDE FRAME OF

STEEL TRAVELLER USED ON QUEBEC BRIDGE.

PLATE VIII



SECTION OF FORWARD BENT

OF STEEL TRAVELLER USED ON QUEBEC BRIDGE

of the traveller when it rested in the position just described. The order in which the members were set in position was; first, lower chord members; second, bottom lateral systems; and last, diagonals, verticals, and upper chord members. The heaviest load raised at one time was a pair of one hundred-ton bottom chord pieces and a pair of seventy-ton top chord pieces. All of the principal tackles were designated by numbers, and their operation was directed by various gestures of the head and arm being, repeated by the foreman. Work was facilitated by a telephone system, which connected the superintendent's office, the traveller, and the storage yards.

An interesting fact to be noted in connection with this work is that the cantilever span was the longest on which work was ever attempted.

Erections of Bridges by the Method of End Launching

A method of erecting bridges,which has frequently been employed under conditions which would not permit the use of falsework,is that of end launching. In 1902 a four hundred ten-foot span was erected in Finland across the Kemi River by this method. The river was crossed at the location of an island, which caused the formation of deep channel in the river on one side of the island and and a shallow channel on the other side. The latter channel is crossed by a series of three spans, varying from one hundred forty-seven to one hundred ninety-seven feet long. The deeper branch has a swift current,and is used for logging in the late

spring and summer. In the winter and early spring masses of ice made it impossible to erect piers in the river. Practically only three months were available in which to erect the bridge, and the use of falsework was therefore impractical.

The bridge was built on shore on the finished railroad embankment, in an axial line with its final position. Four panels were projected out from the shore on falsework, which was erected on a sand deposit. The embankment was paved transversely with timbers along the line of the lower chord of the bridge, and the structure was erected on docking on these timbers. A slideway-track consisting of four I-beams, placed longitudinally, was set on the ties and the roller-end shoes of the bridge were placed in such a position as to slide on the beams, the rollers and sole-plates being omitted from the shoes. An iron plate was placed under the bottom of each shoe to carry the hydraulic presses, which were to furnish the motive power for launching. A timber, lined with a brass plate, was placed under the iron plate, and the bridge was slid directly on this brass plate. Lubricating oil was furnished at regular intervals by means of a pump. The hydraulic press plungers were arranged so as to butt against a shoe or dog, fastened to the stringers in such a way that the bridge would be readily advanced whenever the press had completed a stroke. The river end of the bridge was supported on two pontoons, each ninety-eight feet by nineteen feet in ground plan. The supports were placed under the first and second main panels, and it was necessary to remove a part of the falsework to provide sufficient space for

these. The bridge was built in line, and was guided by cables extending to the shore from the sides and top of the trusses. When the opposite abutment was reached, the end was placed on fixed shoes and was then set in its final position. The pontoons were next placed under the shore end to raise it and to allow the rollers to be placed under the shoes, and the bridge was then lowered into place. The total weight of this bridge was eight hundred tons.

The method of end launching was also employed by the engineer of the Queensland Railways in the erection of a bridge in Queensland. The principle used was the same as that just described, but the work differed in a few details. The shore end of the bridge was placed on trucks running on a narrow-gauge track under each chord, and a ship was used to support the offshore end.

End launching is often used when it is not possible to rest the free end of the bridge on a pontoon or ship. In Canada a bridge with a span of two hundred three feet was erected across a narrow gorge having precipitous sides, at a height of one hundred eighty feet above water. (See Plate IX). Steel suspension ropes 1-5/8 inches in diameter were carried across the gorge to winches operated on the opposite side. These winches rested on rollers on the abutments. Half spans were assembled at each side of the opening, and in this respect differed from the above mentioned methods. The center panel point of each half span was securely bolted to the hinged top of an eighty-foot wooden boom, which was pivoted on a rock face of the gorge. Near the center panels of the bridge were placed roller-bearing shoes which rested on the suspension

PLATE IX

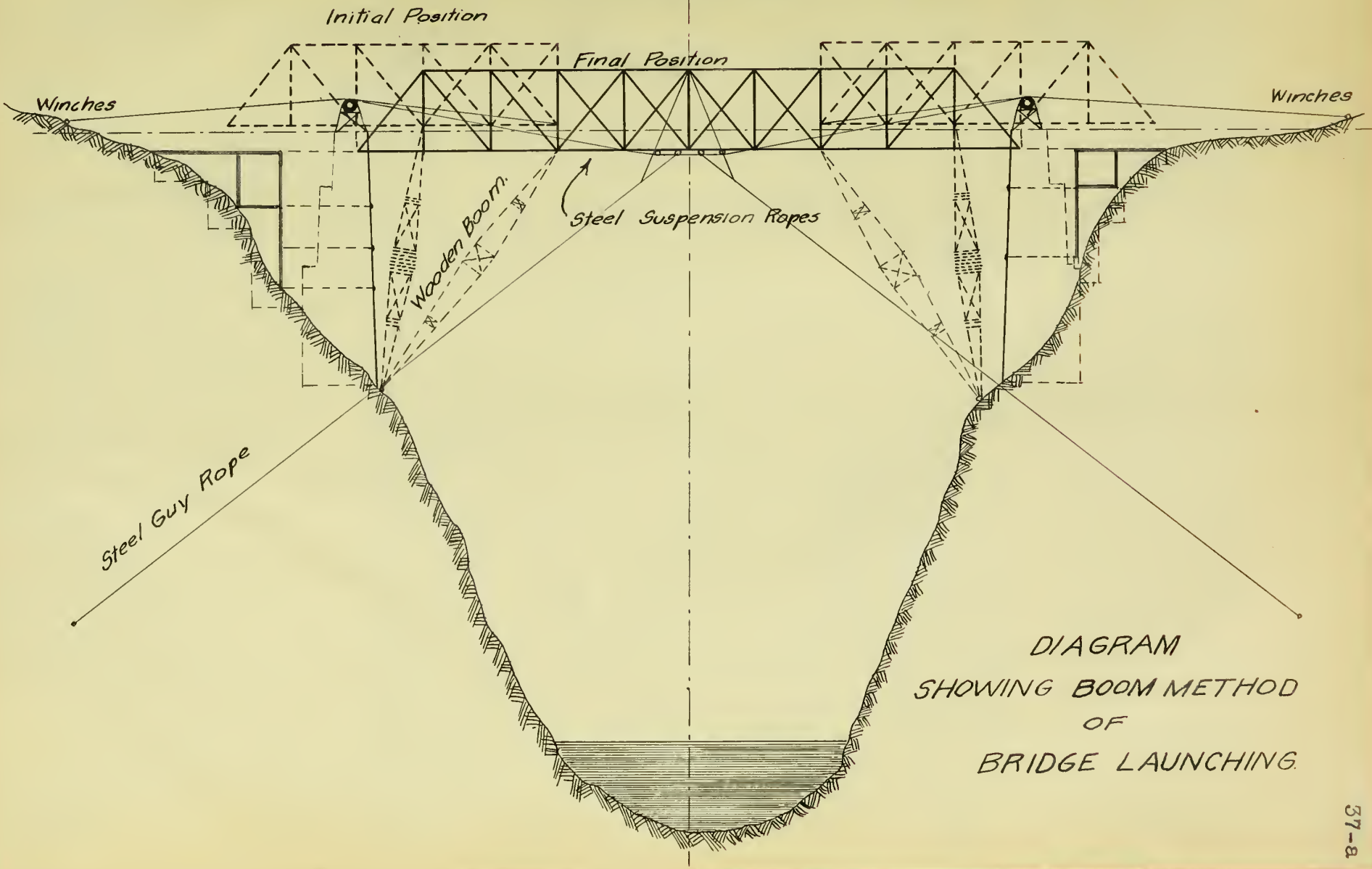


DIAGRAM
SHOWING BOOM METHOD
OF
BRIDGE LAUNCHING.

37-8

ropes, these ropes being stiffened by steel guys. The shore end of the bridge rested on skids, which in turn rested on rails and were counterbalanced as much as possible during launching. Hauling ropes were attached to the forward end of the bridge, and the power was furnished by a locomotive.

When the spans met at the center of the opening the closing up and the adjustments were accomplished by means of jacks and by powerful cam-jaw levers, bolted to the upper and lower chords of the trusses. These were used to hold the spans in position while riveting was being done. The center and cross girders and the gusset plates and spandrels of the upper and lower chords were next placed in position and after these the lateral bracing; floor beams, and joists were placed. In the entire operation of launching the greater part of the weight was borne by the eighty-foot booms. When the trusses met and were assembled, the lowering of the booms caused the trusses to meet at the height of the rails. The time required to close the opening was thirty-six hours, and traffic was suspended for three days during the entire operation. The weight of this bridge was one hundred twenty tons.

COMPARISON OF THE VARIOUS METHODS

The various methods of erection used on steel bridges have been described in detail in the preceding pages, and a comparison of these methods will now be made. This comparison will be divided into two parts. First, a comparison will be made between the various methods described under each one of the following three divisions, viz: plate-girder-bridges, small truss-bridges, and large truss-bridges. Next, a general comparison of all of the methods will be made. This latter comparison will be made chiefly to bring out the characteristics which cause the methods of plate-girder erection to differ from those used in truss erection.

Comparison of the Methods of Erecting Plate-Girder-Bridges

Of the three methods used in erecting small girder-bridges, namely; the use of a derrick placed on the embankment, the use of a derrick placed in the roadway underneath the span, and the method of skidding the finished bridge into place from the car on which it was delivered, the first named is generally the most efficient under ordinary conditions. In railroad work a derrick-car is easily obtained, and it is usually an easy matter to lift the bridge to its place on the abutment. The method of placing the derrick in the roadway is applicable only when the bridge spans an opening on land at a comparatively low height, and it therefore has a limited use. The method of skidding the bridge into its place on the abutment is applicable in most cases,

but it requires a much more difficult operation than either of the other two methods. The girder requires careful guiding, and more men are required to carry out the operation.

The method of utilizing the girder itself in erecting the falsework, which was employed in the erection of the medium-span girder-bridge is more rapid than that of erecting a complete falsework and sliding the girder into place which was employed in the erection of the long-span girder. Economy is practiced in the first case, as the completed girder itself was used to carry a part of the weight of the girders which followed. The latter method, however, is the best to employ when it is impossible to delay the passage of trains for any considerable length of time, as the actual time of placing the new bridge on its abutments is less than that required to erect the shorter-span bridge. Girder-spans of greater length cannot be erected by the derrick-car method, which was used for short lengths, as their weights are too great.

Comparison of the Methods of Erecting Small Truss-Bridges

In comparing the methods of erecting small truss-bridges it is important to note that local conditions play a large part in the selection of a particular method. The three methods which have been described are; the use of a traveller on falsework, the use of a traveller on a cantilever span, and the use of a derrick or gin-pole to lift a completed span or a completed truss into place. The latter method is limited to the construction of spans of ninety feet or less, or account of the impracticability of

handling a weight greater than that of such a bridge. This method is more economical and is just as efficient as the method of erecting falsework for spans up to ninety feet. The use of falsework is not limited by the length of span, but is limited by the strength of the members of the bridge and the height of the bridge above water. The cantilever method is limited by a set of conditions, some of which are opposite to these. It is not limited by the height above water, but is limited by the strength of the members and by the span. The derrick-car and the traveller are used advantageously on both of the last two methods.

Comparison of the Methods of Erecting Large Truss-Bridges

The facts brought out in the preceding paragraph, which treats of small truss-bridges in their relation to the cantilever method and the use of falsework, apply equally well in the case of the erection of large-span truss-bridges by these methods. The traveller is, however, the principal apparatus used, and it is usually of heavier construction when used on cantilever bridges than when used for the erection of other types of bridges.

The method of end launching, as described, has an advantage over the above two methods, because of the fact that the assembling of the parts of the bridge is much simpler. All of the work is done on shore, and the different parts are set in place more readily. The operation of placing the bridge on its abutments requires skillful management, and the expense of erection is thus considerably increased. It is possible to place a bridge on

its abutments in a shorter time by the use of this method than by the use of the other two, and on this account it is imployed in railroad work and in other work in which the stoppage of traffic is not allowed.

Conclusions.

It has been shown in the previous pages that girder-bridges and truss-bridges of very short span can be erected by practically the same methods. Moreover, there is very little difference in the time required or in the apparatus used in the erection of these bridges. For both medium and long spans the methods used differ in several essential features. Girders must be set in place in one piece, but trusses are assembled at the bridge-site, as the erection proceeds. Falsework is used in both methods of erection, but the girder is rolled or skidded into place, whereas the truss-bridge is assembled, piece by piece, on the falsework.

The cantilever method used in truss-bridge erection could not be used in girder-bridge erection, because the entire girder is assembled at the shop. The methods of end launching, described under "Methods of Erecting Large Truss-Bridges" could be used in the erection of a large girder-bridge, provided a ship could be found which would be large enough to carry one end of the heavy girder-bridge.

In deciding upon the method to be used for the erection of any particular bridge all the conditions should be carefully studied, as each bridge has a certain method of erection which is most suitable to it.